Dec. 2013, ULB

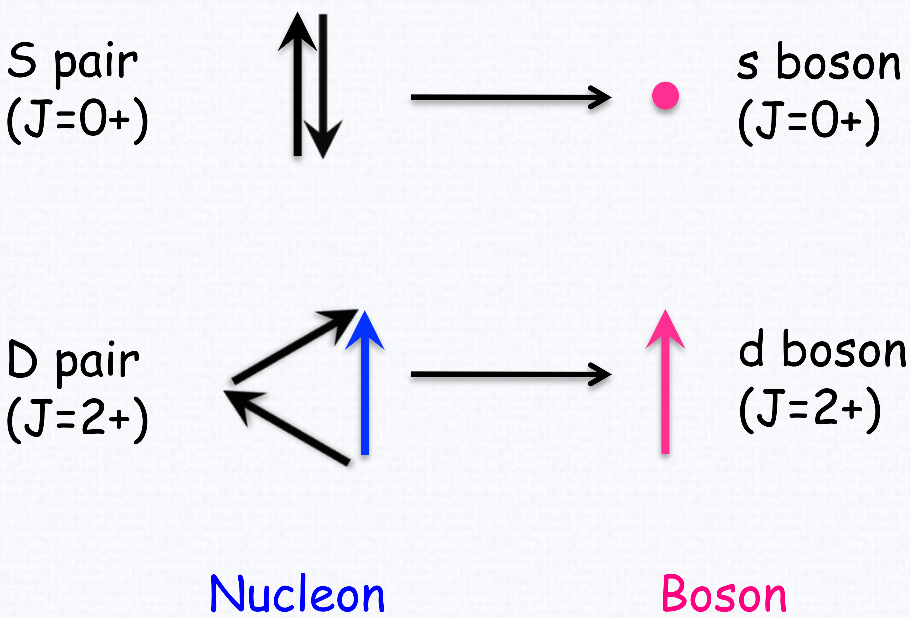
Microscopic IBM for shape coexistence

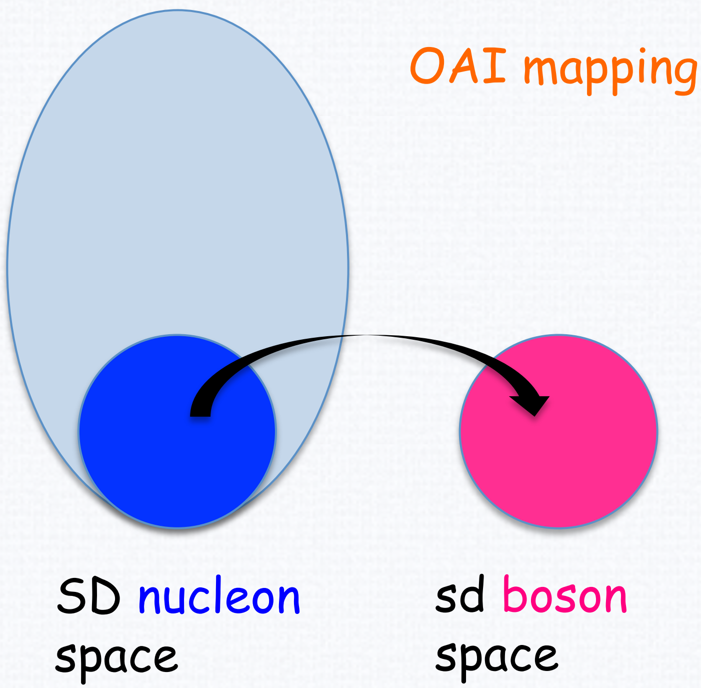
K. Nomura (GANIL)

IBM and the "microscopic foundation"

- Ingredients: collective pairs of valence nucleons
- Derivation from shell model. Good for modest deformation (near spherical and γ-soft systems)
- General cases ?

- A. Arima and F. Iachello (1974)
- T. Otsuka, A. Arima, F. Iachello (1978)
- T. Mizusaki, T. Otsuka (1997)

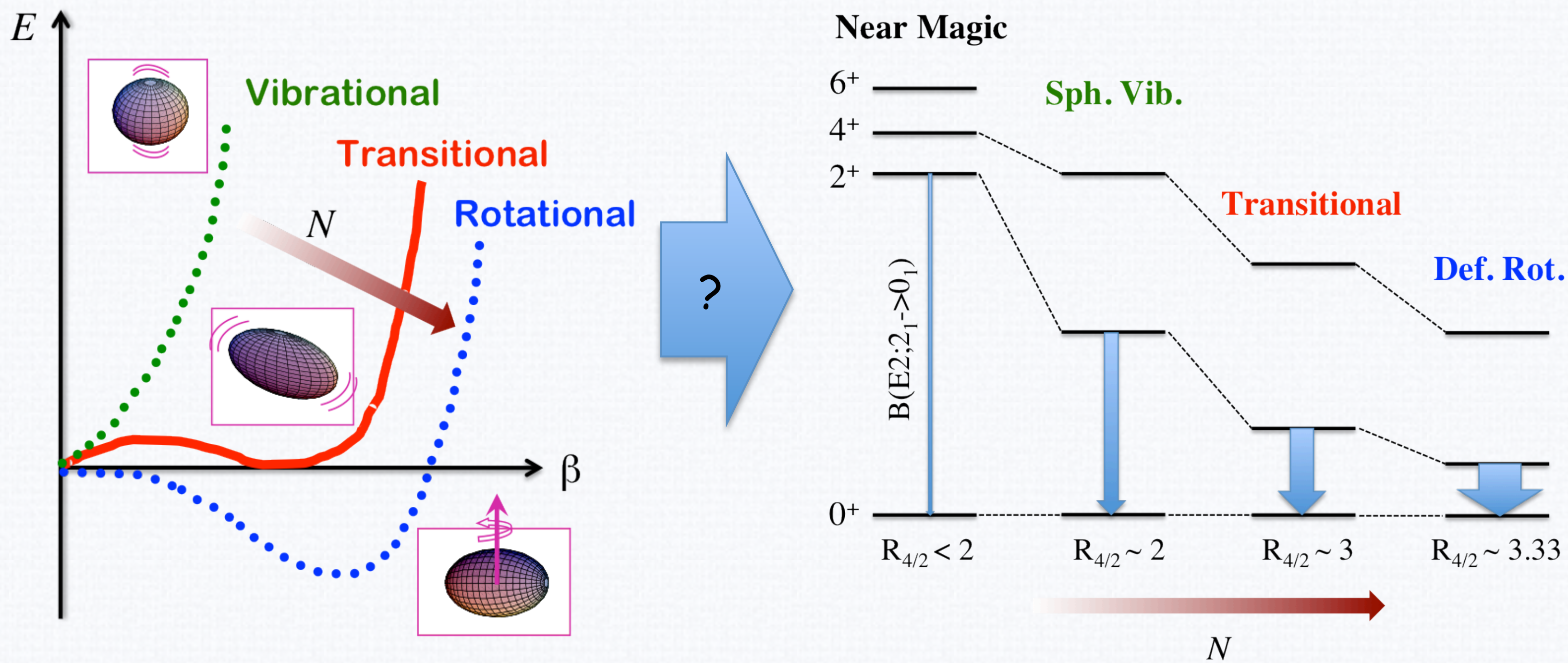




This work – Basic idea

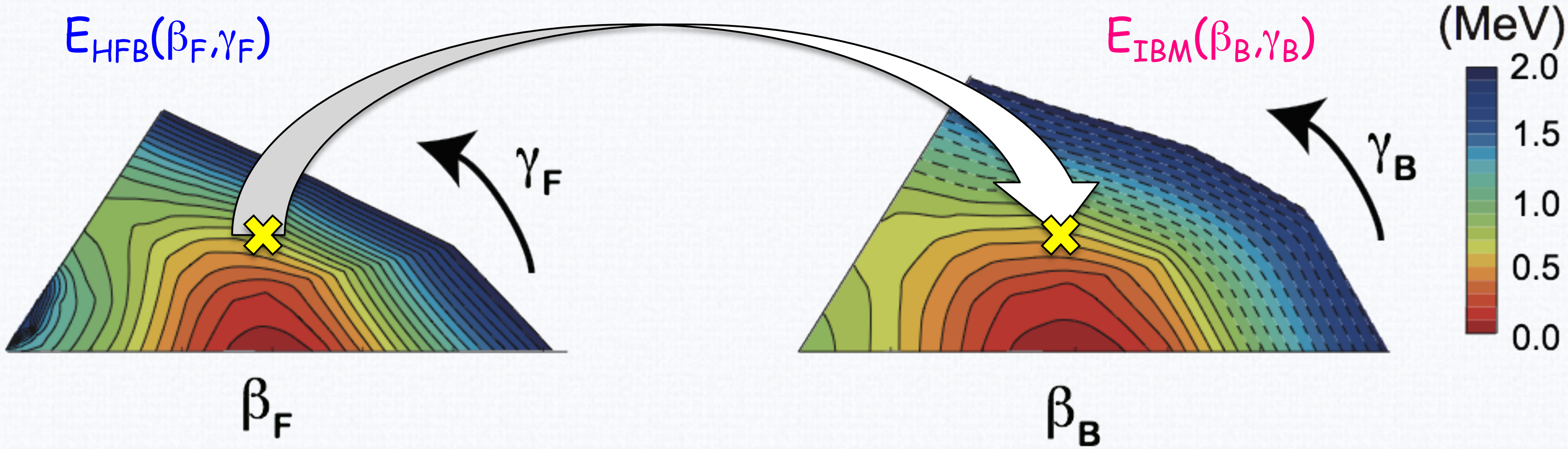
(Potential) energy surface of mean field model (Skyrme, Gogny, RMF, etc) can be a good starting point for intrinsic properties, directly related to shape.

We construct an IBM(-2) Hamiltonian by the mapping from mean-field model.



“Mapping” mean field

K.N., N. Shimizu, T. Otsuka, PRL101, 142501 (2008)



Total energy for nucleon, from the constrained HF(B)

Total energy for a boson condensation (intrinsic state)

An IBM Hamiltonian is determined by the approximate equality: $E_{HFB}(\beta_F,\gamma_F) \sim E_{IBM}(\beta_B,\gamma_B)$
→ energy levels and wave functions with good J, N, P, …

PES fit by Wavelet

- extracts global topology of PES: curvature, minimum, etc.
- fixes IBM parameters unambiguously

scale (frequency)   PES

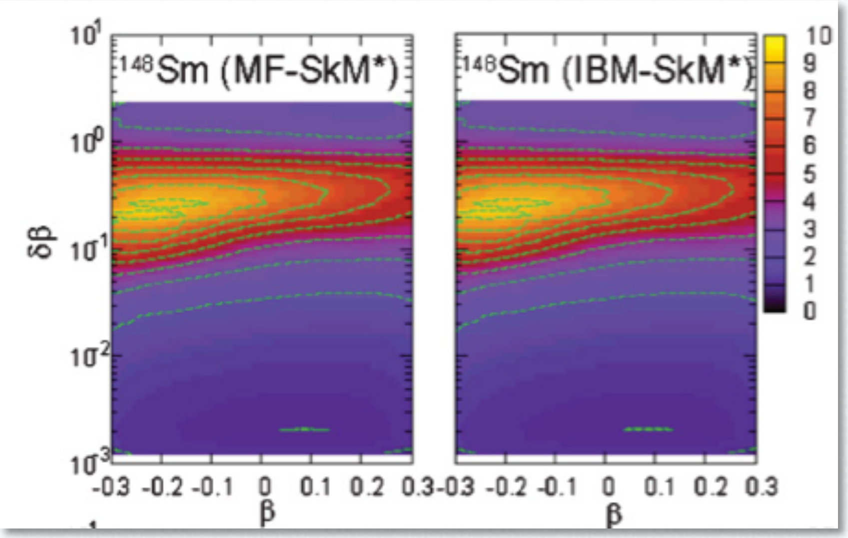
$$\tilde{E}(\delta\beta,\beta) = \frac{1}{\sqrt{\delta\beta}}\int E(\beta')\Phi^{\star}\left(\frac{\beta-\beta'}{\delta\beta}\right)d\beta'$$

coordinate   basis (wavelet)

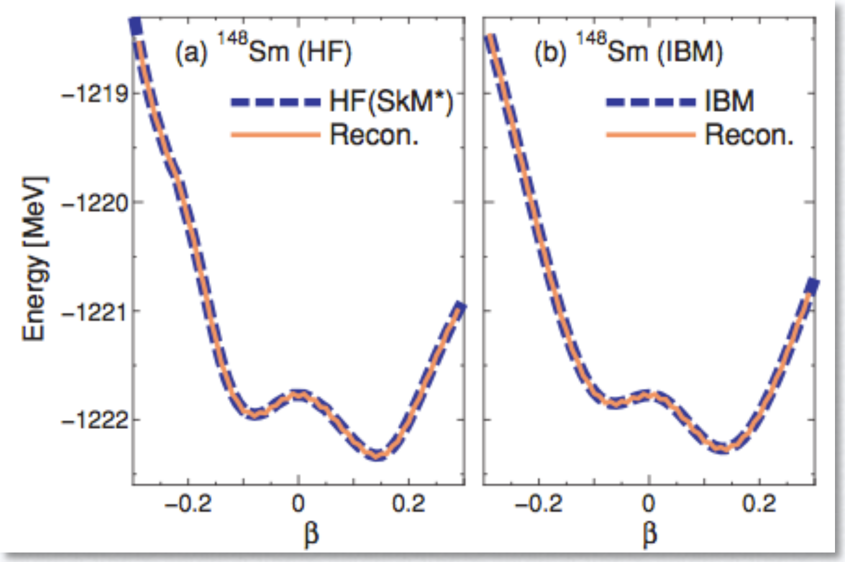
General rules:

- topology around minimum should be reproduced
- do not try to fit $\beta >> \beta_{min}$

χ^2 fit for wavelet transforms



comparison in real space

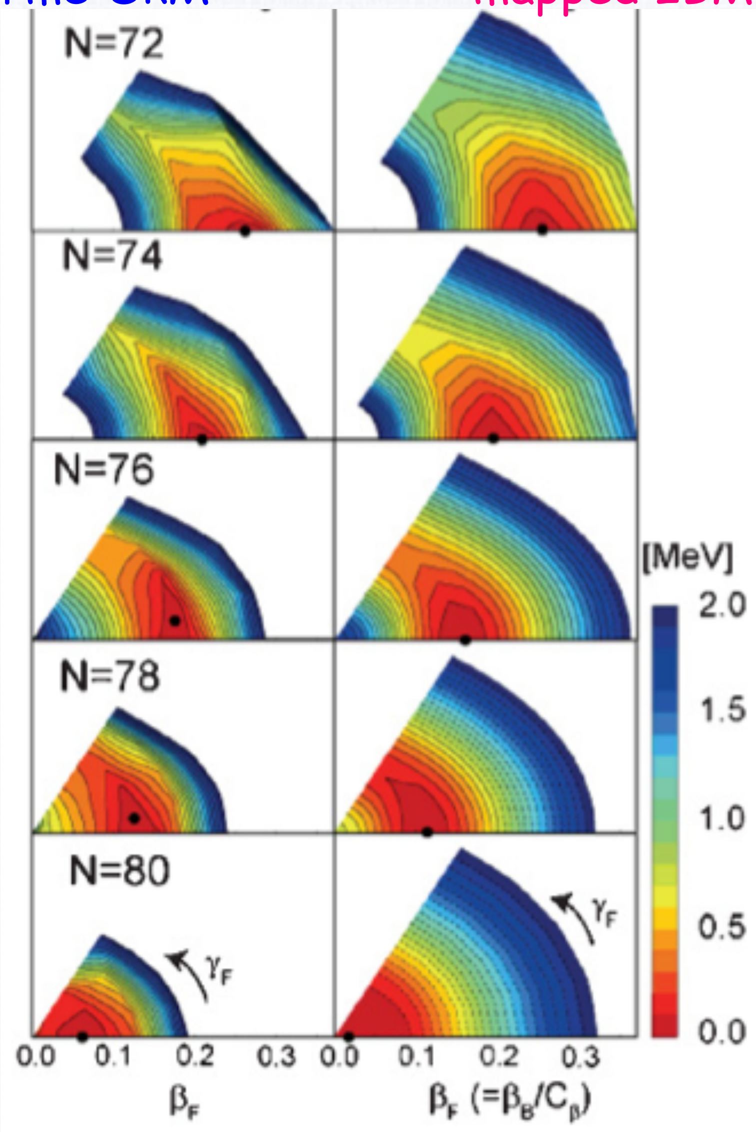


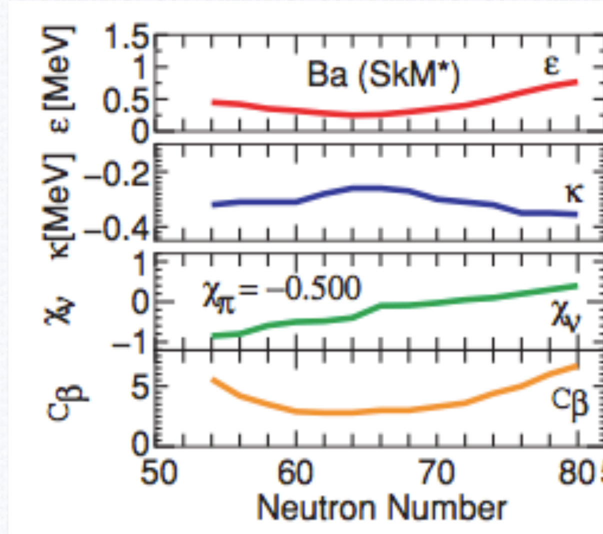
Example: Ba isotopes

K.N., N. Shimizu, T. Otsuka, PRC81, 044307 (2010)

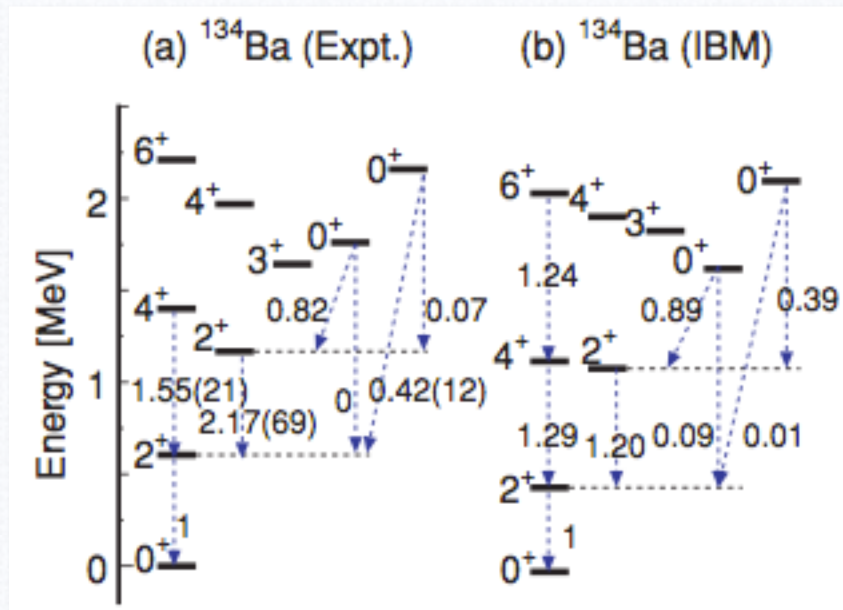
Skyrme-SkM*

mapped IBM

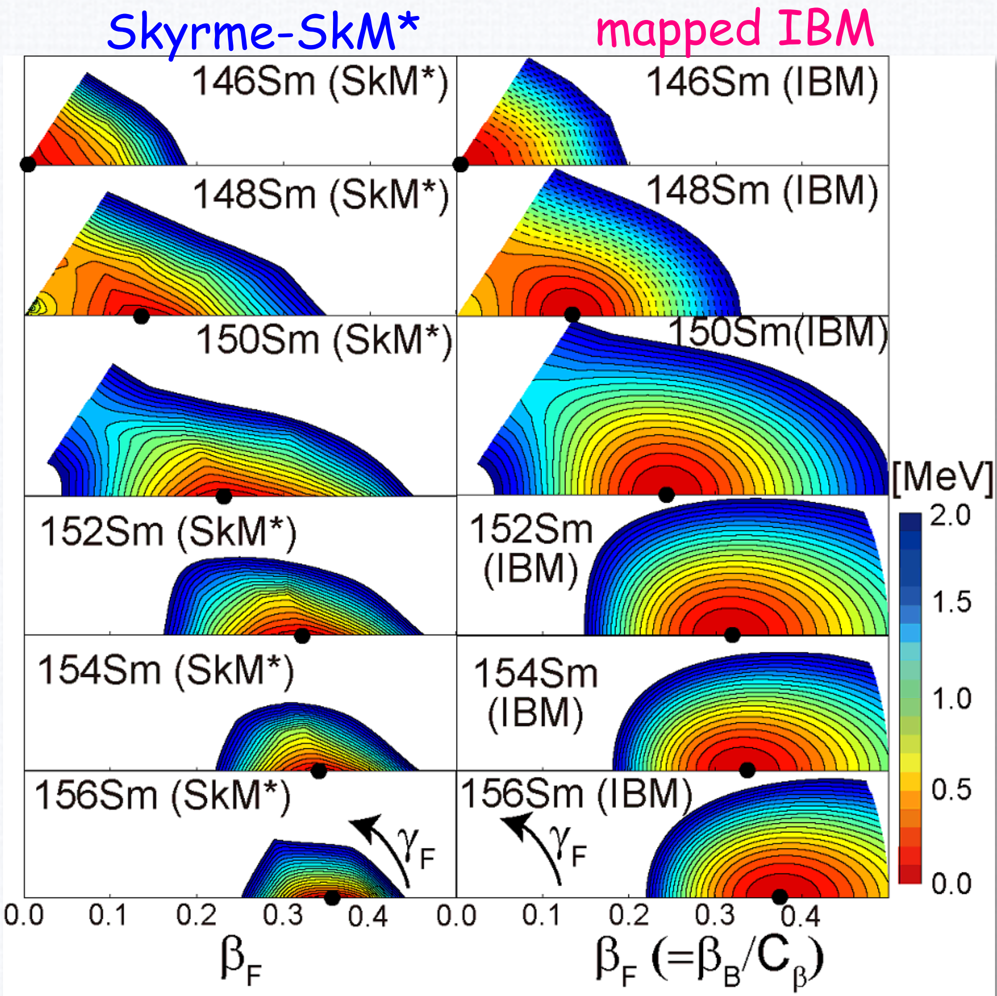


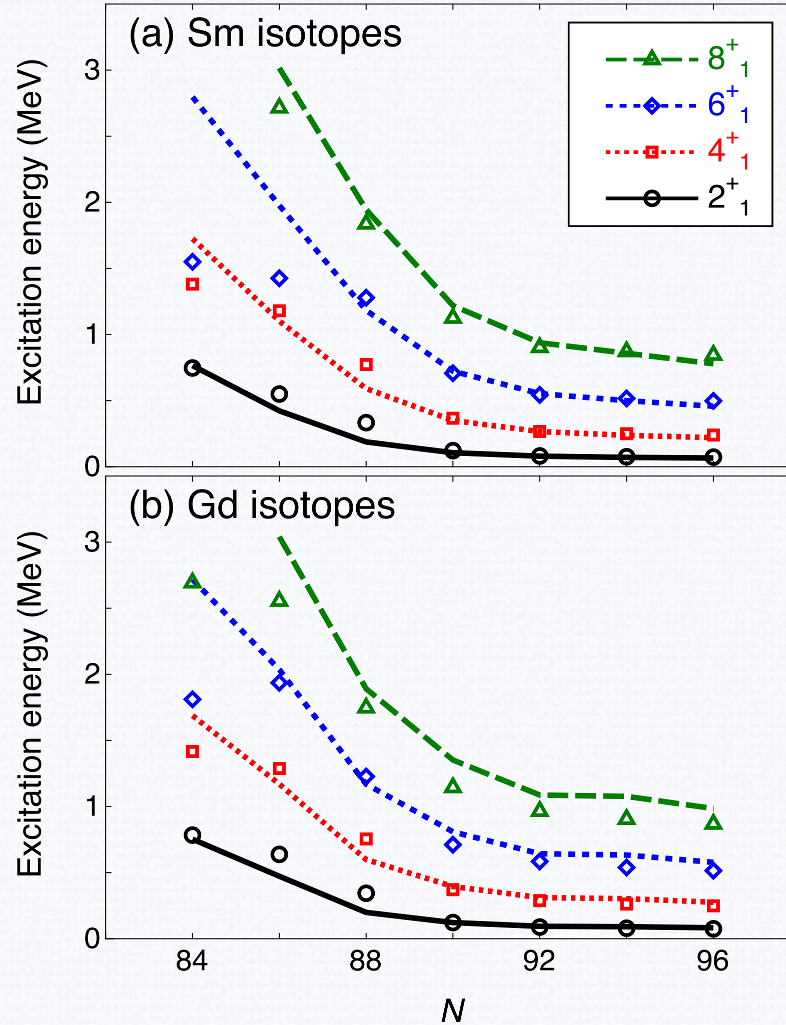


Derived parameters



How about well deformed cases?





K.N., T. Otsuka, N. Shimizu et al., PRC83, 041302(R) (2011)

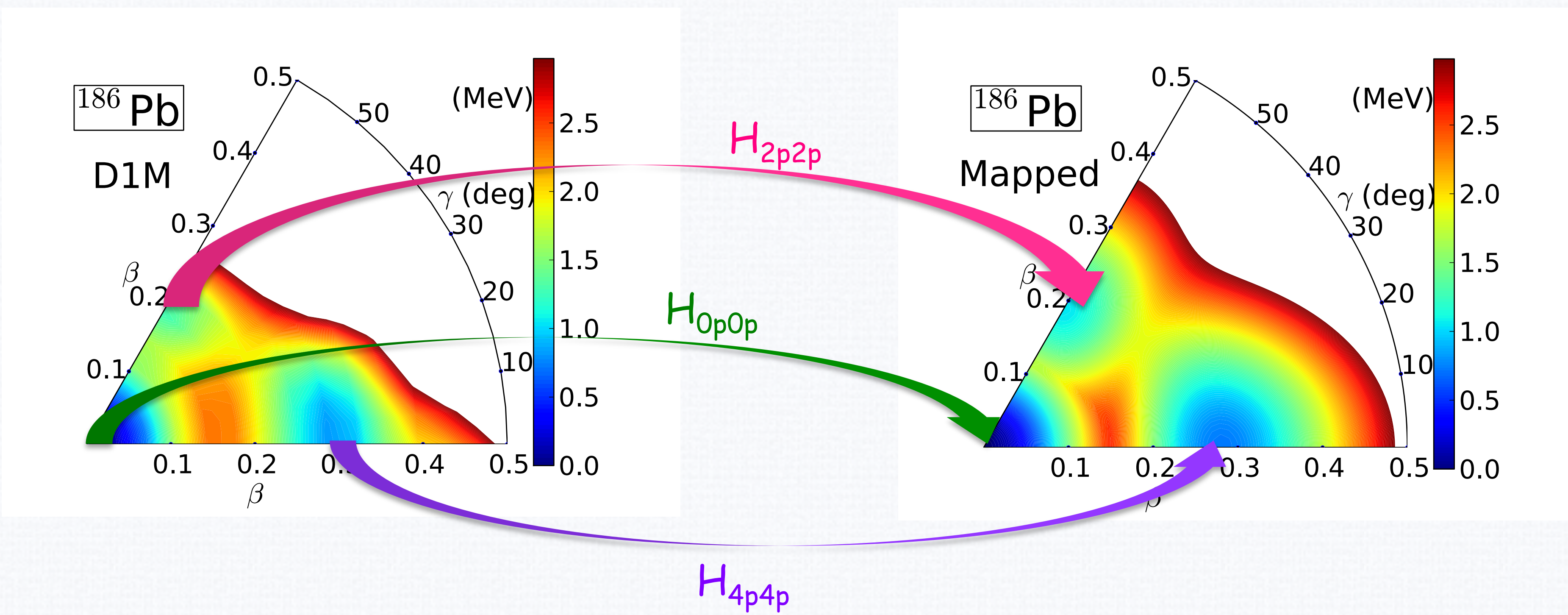
Configuration mixing in IBM

Consider mixing of different Hamiltonians for *ph* excitations, each associated to a mean-field minimum

$$H = H_{0p0h} + (H_{2p2h} + \Delta_{2p2h}) + (H_{4p4h} + \Delta_{4p4h}) + V_{02} + V_{24}$$

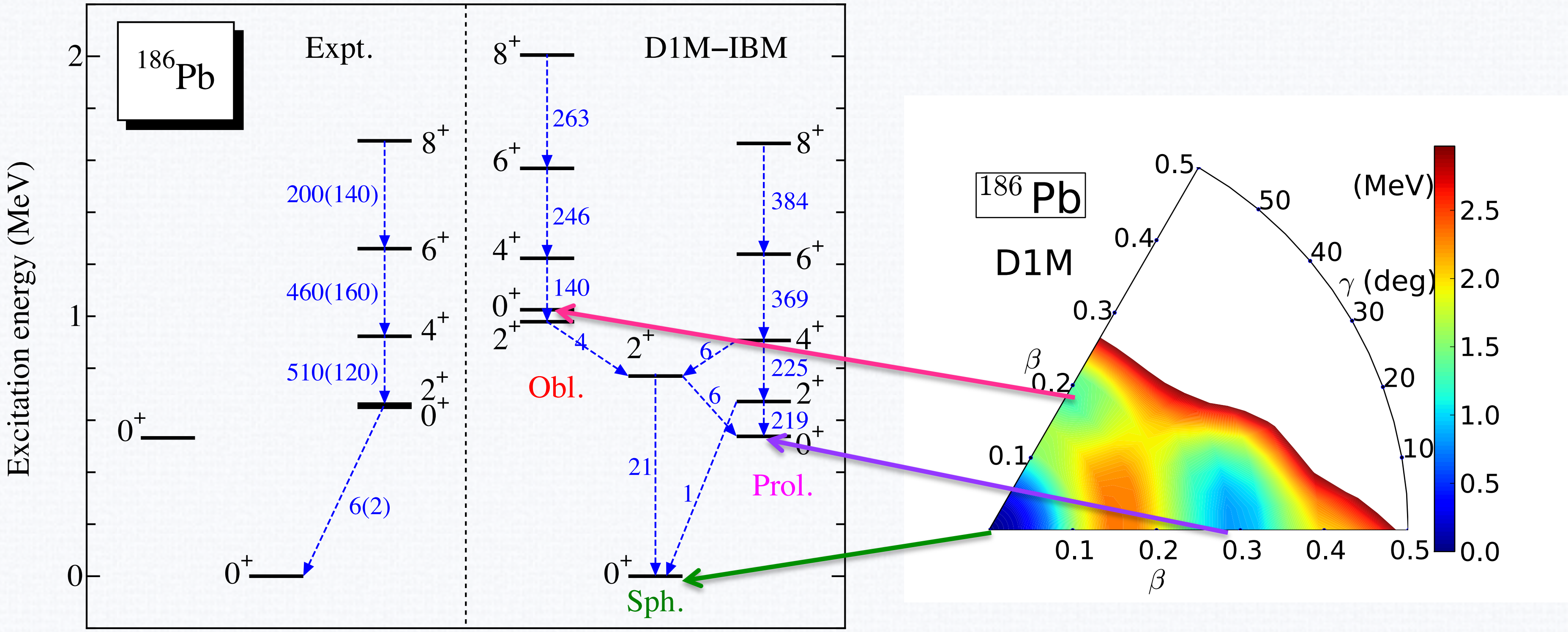
energy difference between minima

barrier height



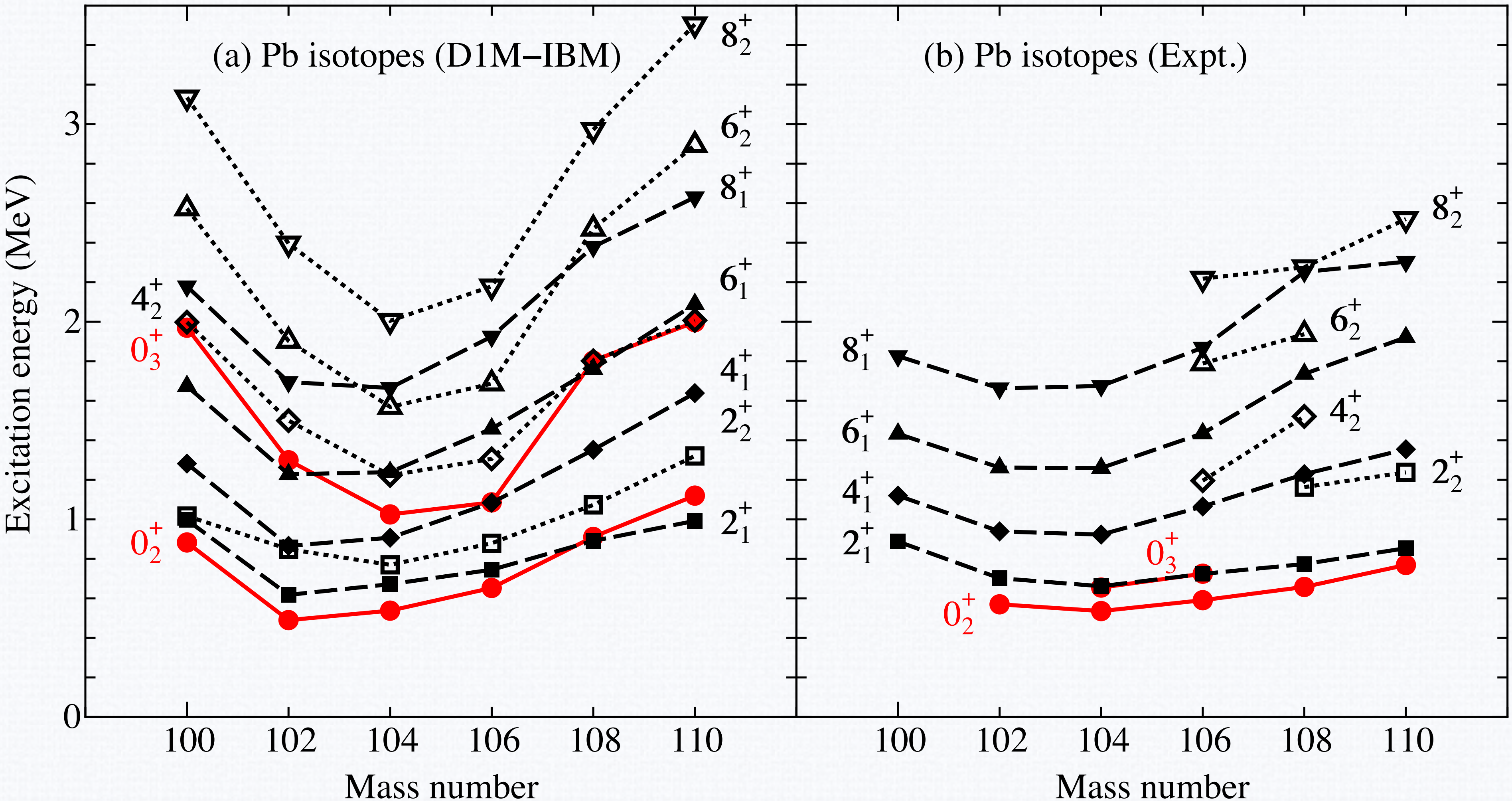
Level scheme: ^{186}Pb

from Gogny-D1M



K.N., R. Rodriguez-Guzman, L. M. Robledo et al., PRC86, 034322 (2012)

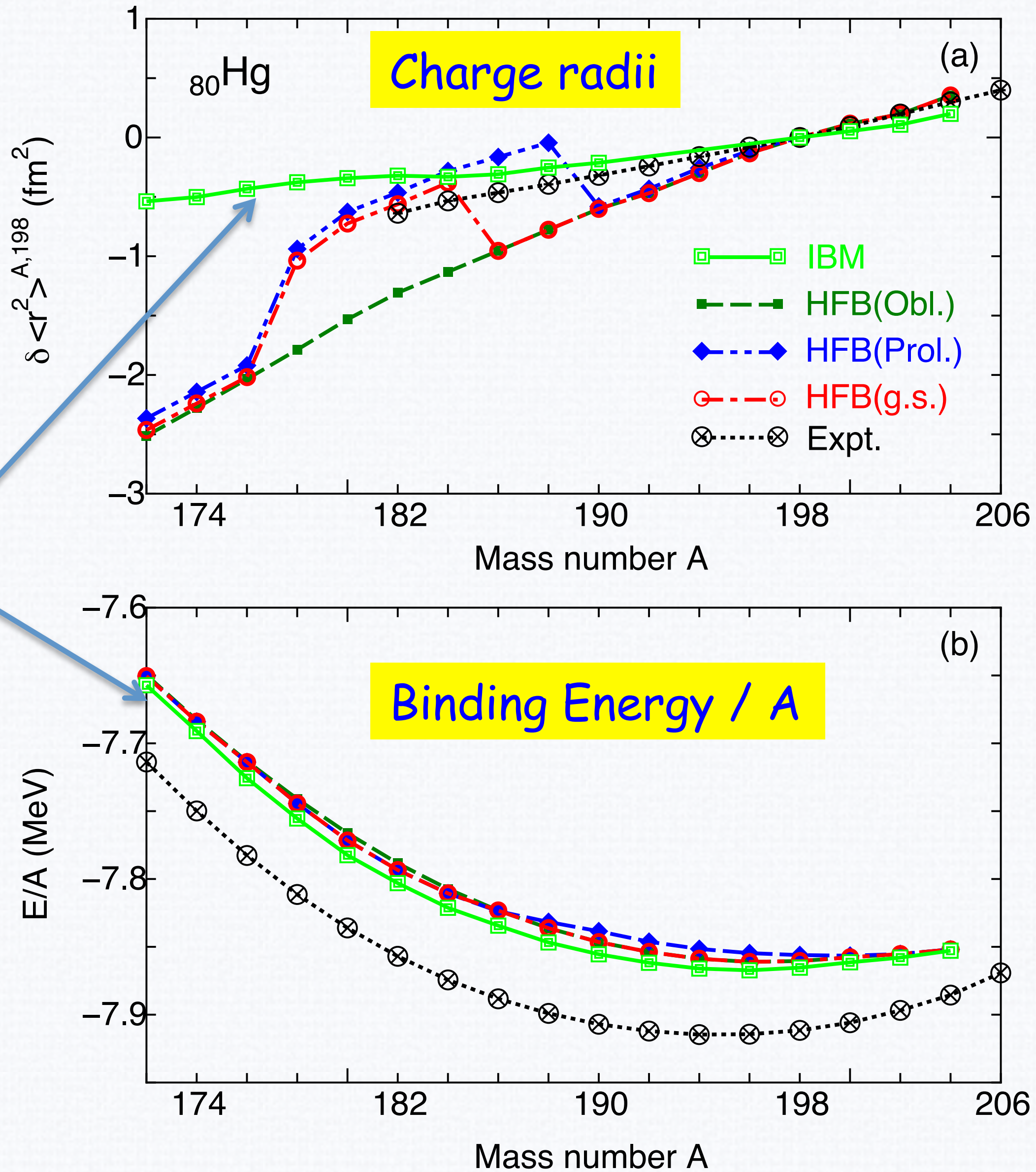
Energy-level systematics in Lead



K.N., R. Rodriguez-Guzman, L. M. Robledo et al., PRC86, 034322 (2012)

Ground-state properties

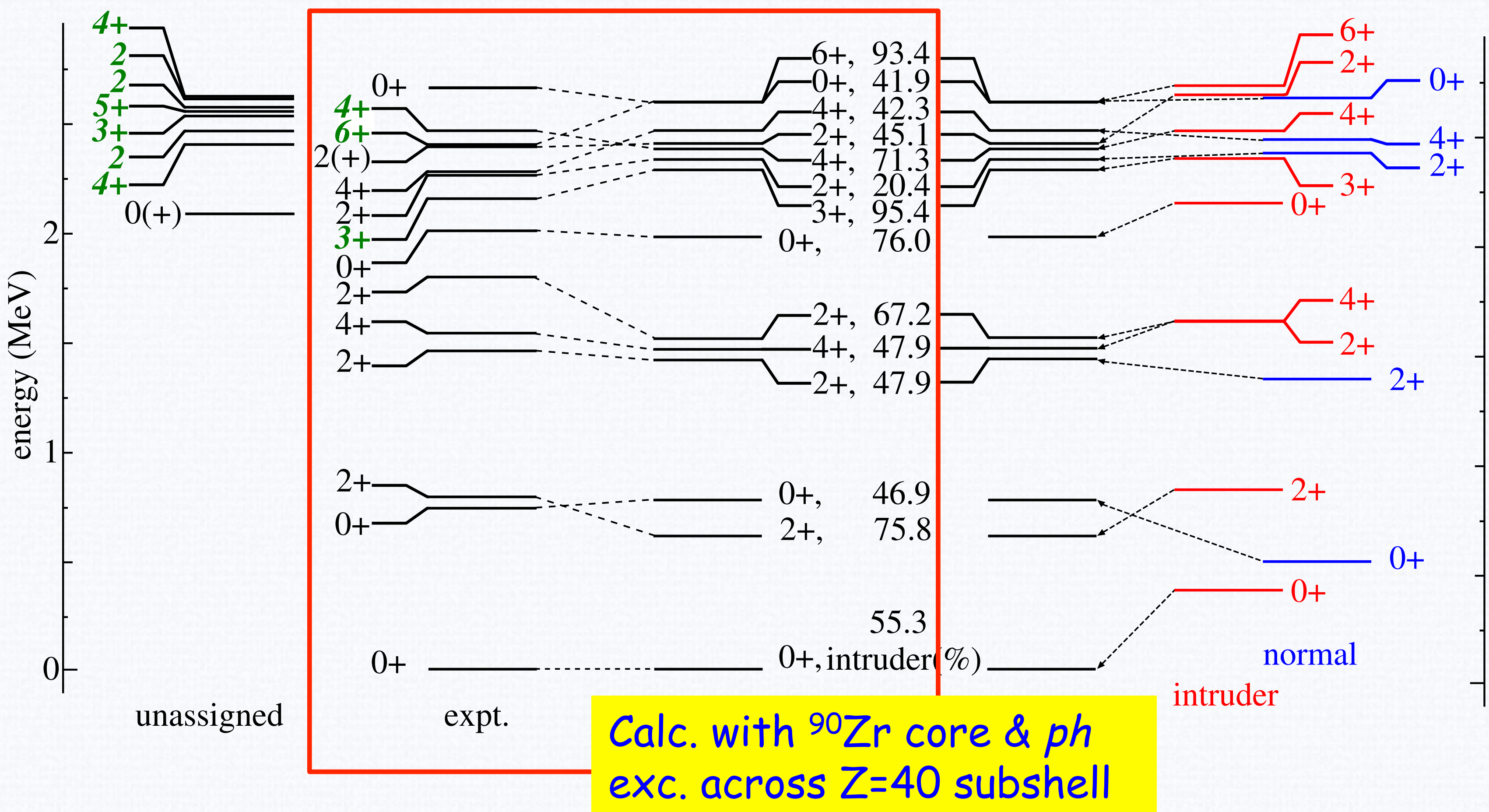
from diagonalization of mapped IBM Hamiltonian



K.N., R. Rodriguez-Guzman, L. M. Robledo, PRC87, 064313 (2013)

Coexistence in A~100: ^{98}Mo

T. Thomas, K.N., V. Werner et al., PRC88, 044305 (2013)



- Coupling of spherical normal and γ-soft intruder configurations
- Large mixing in the ground state

Coexistence in A~100: ^{98}Mo

T. Thomas, K.N., V. Werner et al.,
PRC88, 044305 (2013)

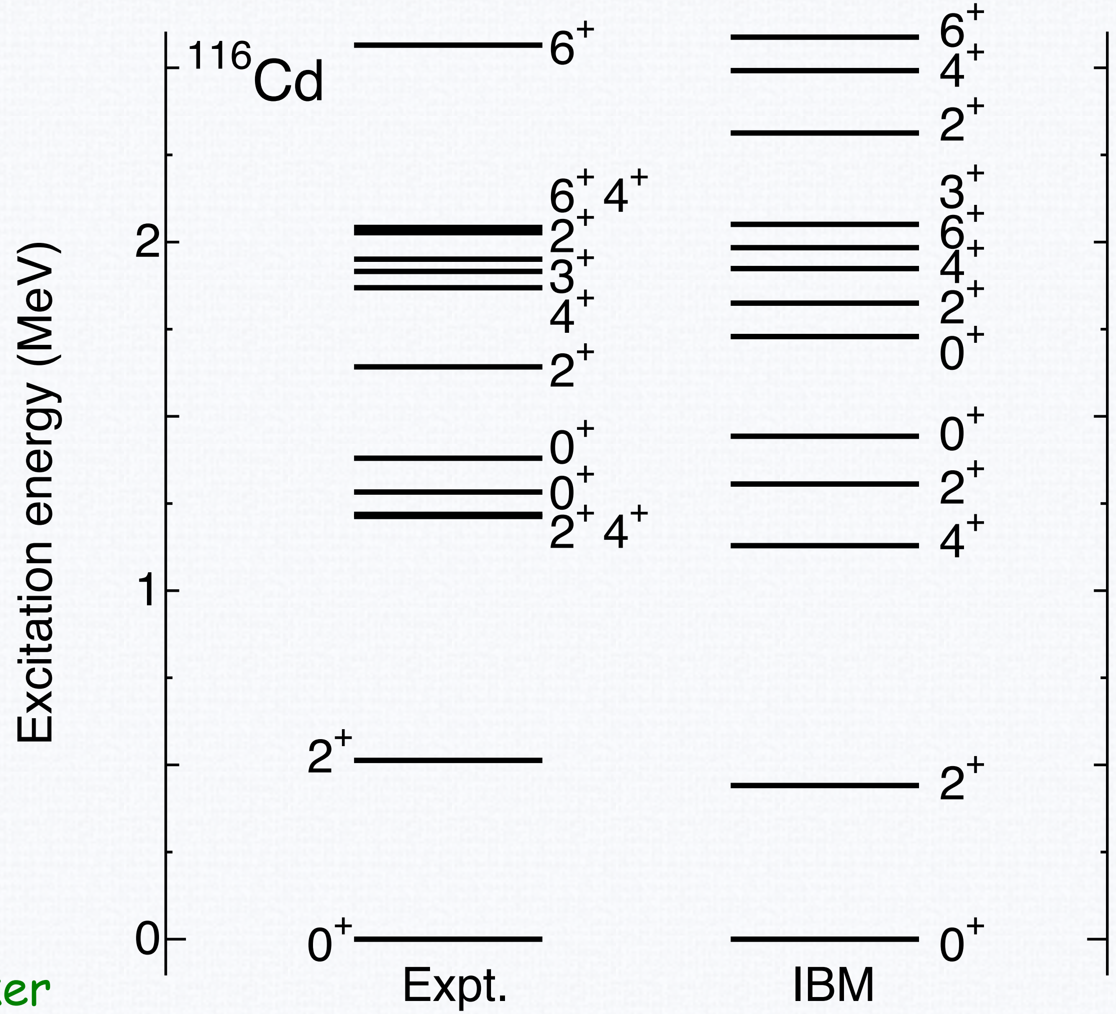
B(E2) (in W.u.)

E_{level} (keV)	J_I^π	E_γ (keV)	J_F^π	$B(E2)_{theor}$	$B(E2)_{expt}$	δ_{expt}
787.26[a]	2_1^+	787.26	0_1^+	27	21.4^{+11}_{-10}	
		52.6	0_2^+	256	280 (40)[b]	
1432.29[a]	2_2^+	644.70	2_1^+	22	47.8^{+132}_{-100}	+1.67 (25)
		697.10	0_2^+	8	2.5^{+8}_{-6}	
		1432.29	0_1^+	0.03	1.0^{+2}_{-1}	
1509.74[a]	4_1^+	722.48	2_1^+	49	$49.1^{+5.5}_{-4.5}$	
1758.32[a]	2_3^+	326.05	2_2^+	13	4.7^{+189}_{-23}	−0.17 (22)
		971.03	2_1^+	6	3.2^{+134}_{-16}	−0.97 (14)
		1023.61	0_2^+	7	7.8^{+286}_{-34}	
2206.74	2_4^+	1419.48	2_1^+	1.3	1.7 (2)	−0.33 (11)
2333.03	$2_5^{(+)}$	900.85	2_2^+	1	1.6^{+8}_{-4}	$-0.15^{+0.19}_{-0.20}$
2343.26[c]	6_1^+	833.52	4_1^+	56	10.1 (4)	

Strong configuration mixing evident from the enhanced $2_1 \rightarrow 0_2$ and $2_2 \rightarrow 2_1$ E2 transitions

More complicated case:
Cd isotopes

- from Skyrme SLy6
- ^{132}Sn core with proton excitation across Z=50



with J. Jolie, P. Van Isacker
et al., in progress

Summary

New formulation of the IBM has been developed. Bridge over the gap between IBM and mean-field model.

- Provides physical observables in lab frame
- Valid for general cases:
    - Sph. vib., def. rot. and transitional nuclei
    - Triaxial system (not mentioned)
    - Shape coexistence and configuration mixing
- Prediction is possible on *heavy* exotic nuclei.

Acknowledgement

My collaborators:

T. Otsuka (U. Tokyo)

N. Shimizu (U. Tokyo)

L. M. Robledo (Madrid)

R. Rodriguez-Guzman (Rice U)

European Commission for the financial aid

Thank you for your attention!

Question for deformed nuclei

Physica Scripta, Vol. 22, 468–474, 1980

Features of Nuclear Deformations Produced by the Alignment of Individual Particles or Pairs

Aage Bohr and Ben R. Mottelson

The Niels Bohr Institute and Nordita, Blegdamsvej 15, DK-2100 Copenhagen, Denmark

Received May 8, 1980

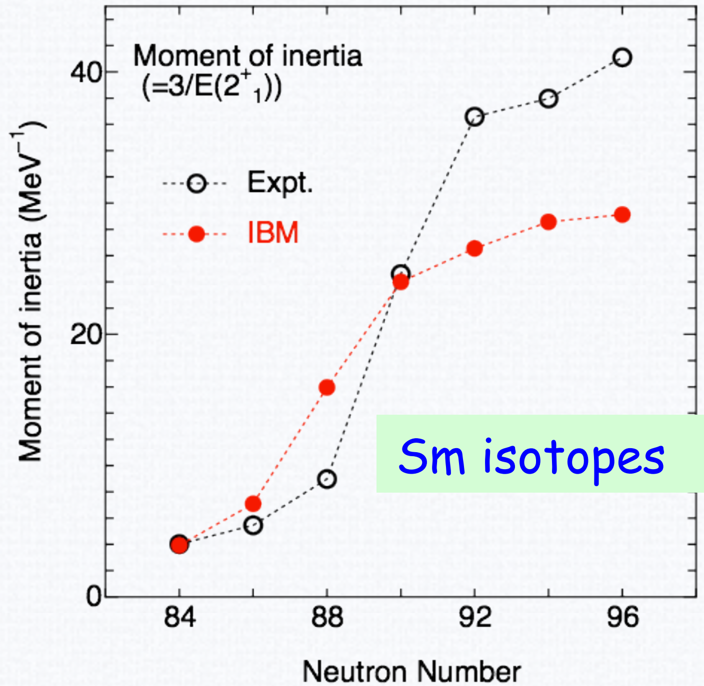
by Bohr and Mottelson, "SD truncation for IBM may not be sufficient for deformed rotational system"

Many debates over the validity of IBM. Unified description?

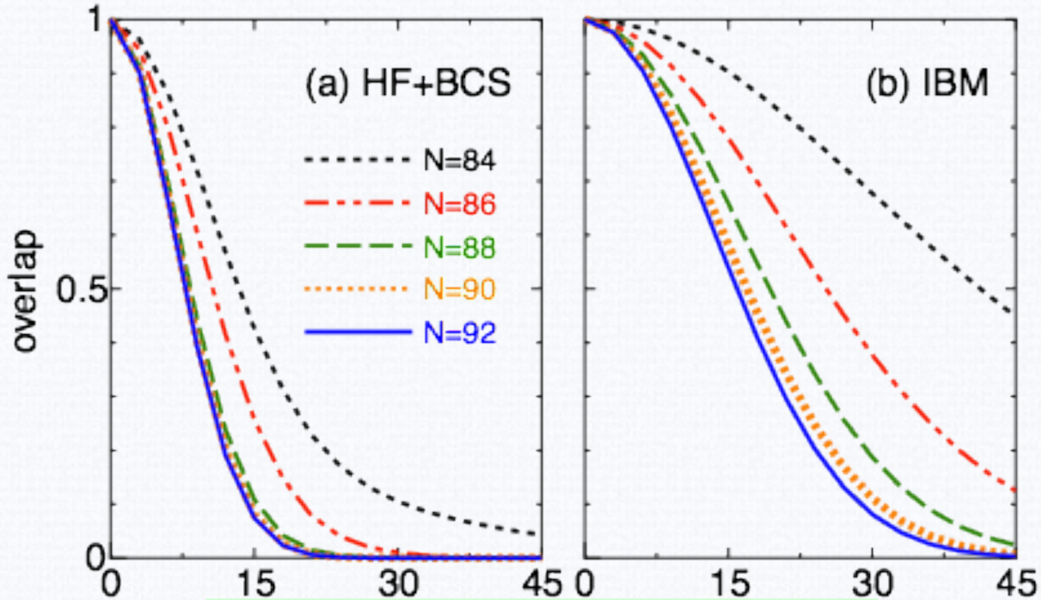
- Nilsson-BCS model (T. Otsuka et al. 1982; D. Bes et al. 1982)
- renormalization of G pair or introducing g boson
  (T. Otsuka & J. N. Ginocchio 1985; T. Otsuka & M. Sugita, 1988)
- conventional boson mapping (M. R. Zirnbauer 1984, etc)
- J projection on intrinsic state (N. Yoshinaga et al. 1984)
- ...

Problem with deformed rotor

Big discrepancy in the rotational band (moment of inertia) of strong axially deformed nuclei.
[cf. question by Bohr & Mottelson]



This can originate from the difference in the rotational property of the intrinsic wave function between fermion and boson.

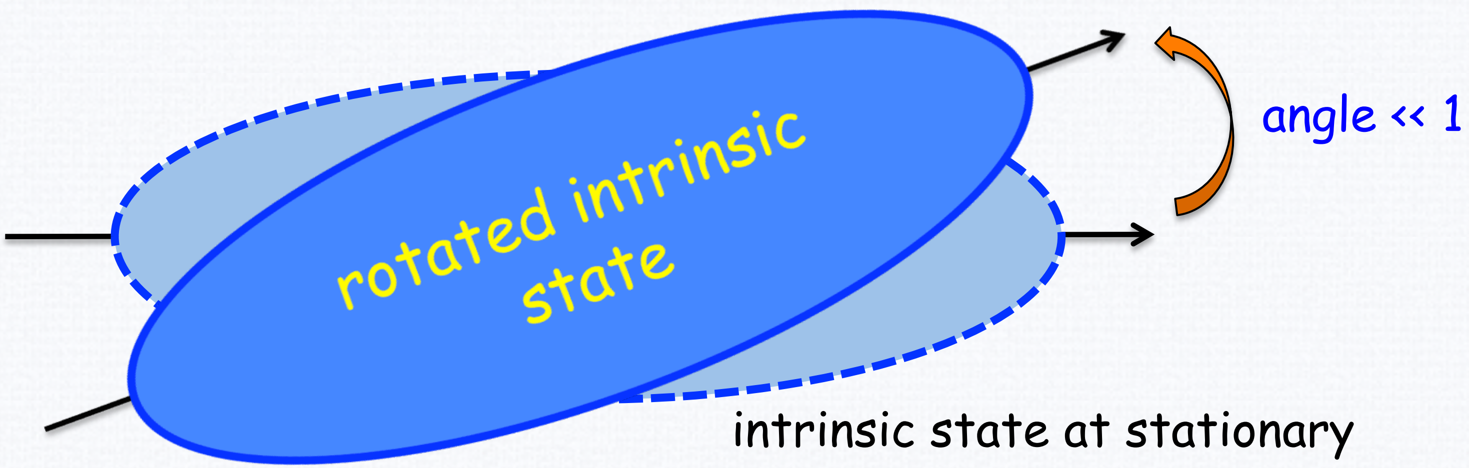


rotation around y-axis [deg]

Mapping "rotational response"

Basic property related to rotation should be reproduced by bosons. We consider the rotational energy (rotational response).

Some interaction term which changes energy but not change the wave function can be included. LL term.



Ref: K.N., T. Otsuka, N. Shimizu, and L. Guo, PRC83, 041302(R) (2011)

Boson Hamiltonian to be fixed

$$\hat{H}^B = \underline{\underline{\epsilon(\hat{n}_{d\pi} + \hat{n}_{d\nu}) + \kappa \hat{Q}_\pi \cdot \hat{Q}_\nu}} + \underline{\underline{\kappa' \hat{L} \cdot \hat{L}}}$$

1) Main part ← Mapping of the PES (static case)

$$\langle q^F | \hat{H}^F | q^F \rangle \sim \langle q^B | \hat{H}^B | q^B \rangle$$

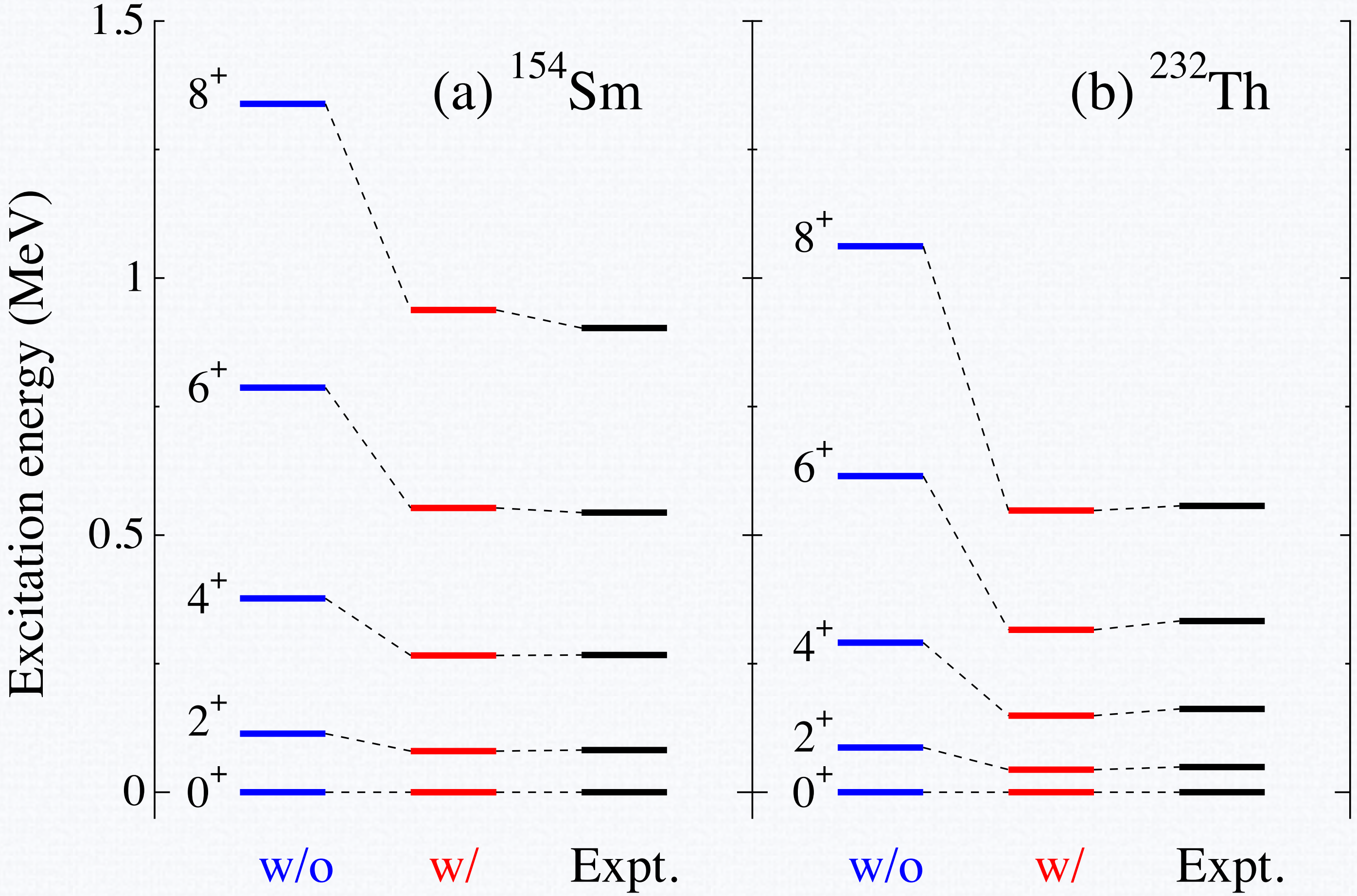
2) LL term ← rotational response at a particular deformation, e.g., minimum (dynamical case). Main part is kept in this step.

$$\delta \langle q^F | \hat{H}^F e^{-i\delta\theta J_y} | q^F \rangle \sim \delta \langle q^B | \hat{H}^B e^{-i\delta\theta J_y} | q^B \rangle$$

angle $\delta\theta \ll 1$

Cranking mom. of inertia is equated between nucleons and bosons.

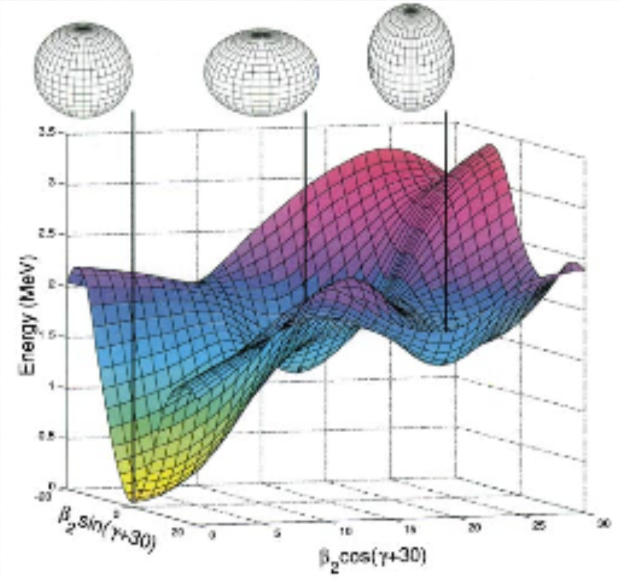
Importance of LL term for rotational band



No adjustment to the experimental data.

Nuclear Structure around ^{208}Pb

Richness in nuclear shape phenomena:



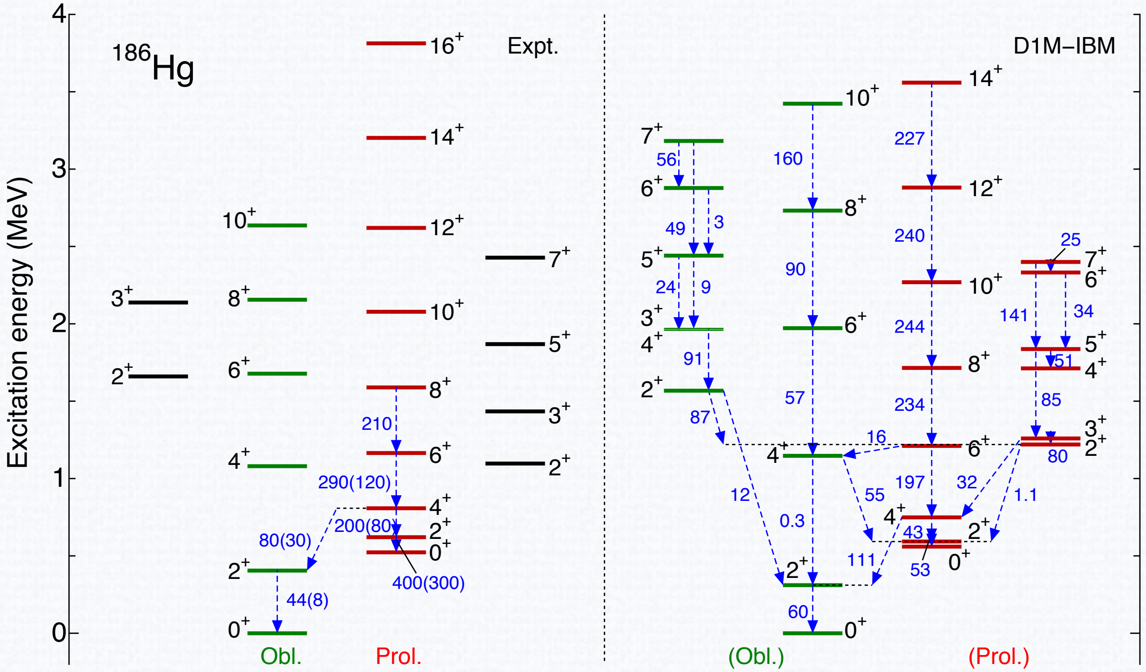
– Competing shapes near the ground state, e.g., 186Pb
– Prolate-oblate transition, soft nuclear shapes
– Superdeformation
– …

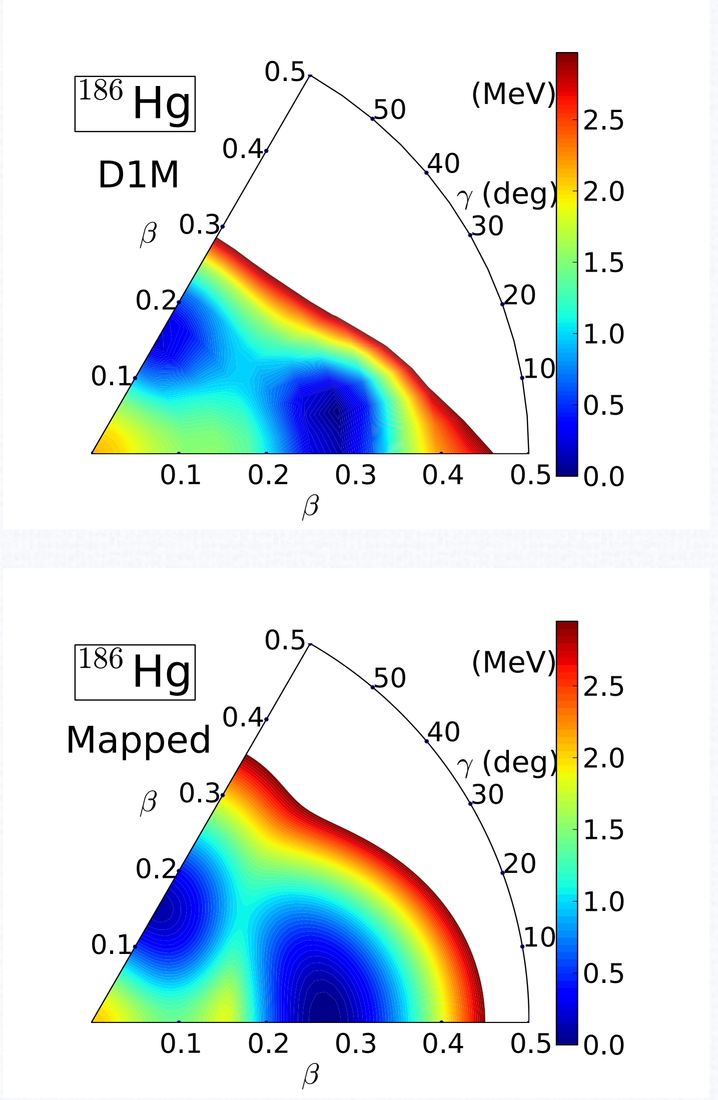
Theory:

(beyond) mean field, phenomenological IBM, … etc.

- Configuration mixing in IBM (Duval & B. R. Barrett, '82)
- Nilsson-Strutinsky method (W. Nazarewicz, '93)
- Skyrme+GCM (T. Duguet et al., '03; M. Bender et al., '04; J. Yao et al., '13)
- Gogny+GCM (R. Rodriguez-Guzman et al., '04)
- RMF (T. Niksic et al., '02)

186Hg





K.N., R. Rodriguez-Guzman, L. M. Robledo, PRC87, 064313 (2013)